Advances in Reflectometric Sensing for Industrial Applications

Synthesis Lectures on Emerging Engineering Technologies

Editor
Kris Iniewski, ***Redlen Technologies, Inc.***

Advances in Reflectometric Sensing for Industrial Applications
Andrea Cataldo, Egidio De Benedetto, and Giuseppe Cannazza
2015

Sustaining Moore's Law: Uncertainty Leading to a Certainty of IoT Revolution
Apek Mulay
2015

Advances in Reflectometric Sensing for Industrial Applications
Andrea Cataldo, Egidio De Benedetto, and Giuseppe Cannazza

ISBN: 978-3-031-79496-4 paperback
ISBN: 978-3-031-79497-1 ebook

DOI 10.1007/978-3-031-79497-1

A Publication in the Springer series
SYNTHESIS LECTURES ON EMERGING ENGINEERING TECHNOLOGIES

Lecture #2
Series Editor: Kris Iniewski, *Redlen Technologies, Inc.*
Series ISSN
Print 2381-1412 Electronic 2381-1439

Advances in Reflectometric Sensing for Industrial Applications

Andrea Cataldo, Egidio De Benedetto, and Giuseppe Cannazza
University of Salento

SYNTHESIS LECTURES ON EMERGING ENGINEERING TECHNOLOGIES #2

ABSTRACT

This book offers a comprehensive review of innovative measurement and monitoring solutions based on time domain reflectometry (TDR). This technique has numerous applications in several fields, ranging from the characterization of electronic devices to quality control of vegetable oils. However, most of the well-established TDR-based monitoring solutions rely on local or punctual probes; therefore, typically, to monitor large areas/volumes, a high number of probes must be employed, with the consequent maintenance and management requirements. On such bases, in the last few years, the authors have carried out extensive research on the use of diffused wire-like sensing elements to be used as probes for TDR measurements. The basic idea has been to extend the principles of punctual TDR-based monitoring to multi-purpose networks of diffused, sensing elements (SE's), embedded permanently within the systems to be monitored (STBM's). These SEs can be tens of meters long, and can follow any desired path inside the STBM.; in fact, they are inactive inside the STBM. Additionally, these SE's are passive (i.e., they do not require batteries) and their sensing ability is activated, by the TDR signal, when they are connected to the measurement instrument. In addition to this, these SE's are completely maintenance-free.

Starting from these considerations, this book addresses the use of low-cost, passive, flexible, wire-like SE's to be used in conjunction with TDR.

This book also provides several application test cases, with hints for practical implementation of the described monitoring systems.

KEYWORDS

microwave reflectometry, reflection coefficient, leak detection system, moisture monitoring, structural health monitoring, diffused monitoring, smart monitoring, time domain reflectometry, dielectric permittivity, dielectric characterization

Contents

Preface

This book arose out of work by the three authors over a number of years in their research activity on the development of innovative measurement and monitoring solutions based on time domain reflectometry (TDR). Those who are reading this book are probably already familiar with TDR and with its numerous applications in several fields, ranging from the characterization of electronic devices to quality control of vegetable oils. However, most of the well-established TDR-based monitoring solutions rely on local or punctual probes; therefore, typically, to monitor large areas/volumes, a high number of probes must be employed, with the consequent maintenance and management requirements. On such bases, in the last few years, the authors have carried out extensive research on the use of diffused wire-like sensing elements to be used as probes for TDR measurements. The basic idea has been to extend the principles of punctual TDR-based monitoring to multi-purpose networks of diffused, sensing elements (SE's), embedded permanently within the systems to be monitored (STBM's). One of the major advantages of such sensing systems is that the SE's may be tens of meters long and can follow any desired path inside the STBM, thus allowing to obtain a diffused profiling with a single sensing element. Furthermore, these SE's are passive (i.e., they do not require batteries); in fact, they are inactive inside the STBM, and their sensing ability is activated, by the TDR signal, when they are connected to the measurement instrument. In addition to this, these SE's are completely maintenance-free.

Starting from these considerations, this book addresses the use of low-cost, passive, flexible, wire-like SE's to be used in conjunction with TDR. The book comprises four chapters.

Chapter 1 begins with a concise description of the basic principles of TDR. Because this book is intended to provide a hands-on approach, the theoretical content is kept to the minimum that suffices for providing the reader with a clear understanding of the physical principles behind the described technologies. Chapter 1 also provides an overview of the most common and well-established TDR applications and a survey of the traditional SE configurations used in TDR measurements.

Chapter 2 describes the use of diffused, wire-like SE's and TDR for leakage detection in underground water pipes. This system has reached a high level of maturity; in fact, at the time of writing of this book, this system has just been made commercially available (with the commercial name of S.I.M.P.Le., acronym of System for Identifying and Monitoring Pipe LEaks) and has also just been implemented (in the South of Italy) by the largest European water operator.

Chapter 3 describes a diffused TDR-based measurement system for moisture monitoring in building structures. Also, this system relies on flexible, diffused bi-wire SE's that are permanently embedded within the structure to be monitored. The reported experimental test-cases demonstrate the potential of the proposed TDR-based system (in conjunction with wire-like

SE's) for moisture content monitoring of building structures, both for *ex-ante* monitoring and *ex-post* monitoring applications.

Finally, Chapter 4 provides the description of a TDR-based system for monitoring liquid level inside tanks. In particular, two configurations (both employing flexible, diffused wire-like SE's) are described: one suitable to be employed on metallic containers and the other to be employed on non-metallic containers. These liquid-level monitoring systems are characterized by low cost and high adaptability; in fact, the SE's can be adapted to the shape of the containers and can be used also for containers taller than a few tens of meters. Additionally, for non-metallic containers, the system configuration becomes completely noninvasive, thus making this solution attractive for industrial applications involving toxic, pressurized, hazardous, or sterilized liquids.

Overall, the present book provides a collection of experimental test-cases for each of the considered applications, in the intent to provide the reader with a sensible and practical perspective on the implementation of the described TDR-based monitoring systems. While additional experiments are to be carried out in order to further enhance the accuracy of the described TDR-based monitoring solutions, the ultimate challenge, in the long-term, will be to realize a comprehensive monitoring platform (based on *sensing elements networks*), which could possibly be interfaced with a common (single) technological infrastructure and which could be simply controlled through smartphones or computer-based applications.

Andrea Cataldo, Egidio De Benedetto, and Giuseppe Cannazza
December 2015

Acknowledgments

We would like to thank Prof. Nicola Costantino, Eng. Antonio De Leo, and Eng. Marcello Miraglia (Acquedotto Pugliese S.p.A., Bari, Italy) for believing in our *S.I.M.P.Le.* leak-detection project from the very beginning (even when it was at a very early stage), and for dedicating so much of their time and effort to the implementation of the first ever water pipe network equipped with S.I.M.P.Le.

We would also like to thank to Prof. Mario Savino (Politecnico di Bari, Bari, Italy) for the fundamental theoretical discussions and Prof. Nicola Giaquinto (Politecnico di Bari, Bari, Italy) for his support and technical collaboration in the implementation of the efficient processing algorithms.

Many thanks also to Prof. Emanuele Piuzzi (Sapienza University of Rome, Rome, Italy) for his precious insight into the microwave world.

Also, thanks to Giovanni Leucci (National Research Council - Istituto per i Beni Archeologici e Monumentali), for his suggestions in our work related to water content monitoring of building structures.

Finally, thanks to Eng. Antonio Masciullo (University of Salento, Lecce, Italy) for the practical support and sensible advice throughout our research activities.

Andrea Cataldo, Egidio De Benedetto, and Giuseppe Cannazza
December 2015